

## Spatial atrial vectorcardiogram in naturally occurring atrial flutter in man

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*In 12 cases of 'classical' atrial flutter, the flutter waves were best seen in scalar leads II, III, and aVF. The planar atrial flutter vector loops were directly recorded using the Frank system of lead placement. The spatial loops were of distorted oval or figure-of-eight pattern, with their long axes in a vertical plane; there was a slow upward component and a more rapid downward path lying anterior to, and usually to the right of, the slower component.*

*In one case of 'atypical' flutter, the scalar electrocardiogram showed shallow waves in the limb leads and 'dome and dart' flutter waves in lead VI, and the spatial flutter vector loop, which had a distorted figure-of-eight form, had an anteroposterior long axis and a rapid backward path, lying mainly to the right of, and above, the slower forward path. Null points were difficult to locate. Though the spatial atrial vectorcardiograms demonstrate the continuous atrial activity well, they do not differentiate between depolarization and repolarization, nor do they provide undisputed evidence of a circus rhythm.*

The mechanism of the electrical excitation of the atria in naturally occurring atrial flutter in man is still far from certain. In a review of the published work in 1966, Scherf considered that experimentally induced atrial flutter could be caused by the rapid discharge of a single focus of stimulation, whereas a theory of circus movement still required proof; he stated that there was no definite evidence for either mechanism in clinical atrial flutter. On the other hand, Rytand (1966) summarized all the evidence in favour of circus movement and added fresh evidence to suggest that when clinical atrial flutter is defined according to the criteria of Lewis (1925) it arises as the result of a circus movement in the atria.

Vectorial analysis of flutter waves, indirectly derived from scalar recordings, were made by Lewis, Drury, and Iliescu (1921) and, more recently, by Decherd, Ruskin, and Herrmann (1945), Cabrera and Sodi Pallares (1947), and probably also by Grishman *et al.* (1950). Mirowski and Alkan (1967) used a vectorial approach, based on the horizontal and frontal planes, to analyse the scalar electrocardiograms of 4 cases of flutter which were characterized by 'dome and dart' configuration of the flutter waves in lead VI.

There is a remarkable scarcity of directly recorded

vectorcardiograms of human atrial flutter. Duchosal and Sulzer (1949) published two examples of flutter loops probably recorded from the same patient. Rytand, Toole, and Weinreb (1966) mentioned the results of 'vectorcardiography' in an abstract of a communication, but the details are not explicit. Rosen, Lau, and Damato (1969) illustrated the 'P loop' of the vectorcardiogram recorded from a patient with 'typical' atrial flutter, but it is not clear whether this was naturally occurring atrial flutter or a tachydysrhythmia induced by rapid pacing of the coronary sinus region during right heart catheterization. Alderman *et al.* (1972) have since published computer-processed atrial vectorcardiograms from only 3 patients with naturally occurring atrial flutter.

We therefore decided to study a series of patients with naturally occurring atrial flutter by direct spatial vectorcardiography, and in this paper we report the results.

### Patients and methods

Vectorcardiograms were recorded, using a photographically recording Cambridge vectorcardiograph (No. C. 53811) (Cameron, Lawrie, and Wright, 1959), in 13 patients whose scalar electrocardiograms showed atrial flutter.

Twelve patients had 'classical' atrial flutter as defined by Lewis (1925). This is illustrated in Fig. 1 which shows



FIG. 1 Atrial flutter with flutter waves as defined by Lewis (1925), best seen in leads II and III. In lead V1 an isoelectric interval may be present.

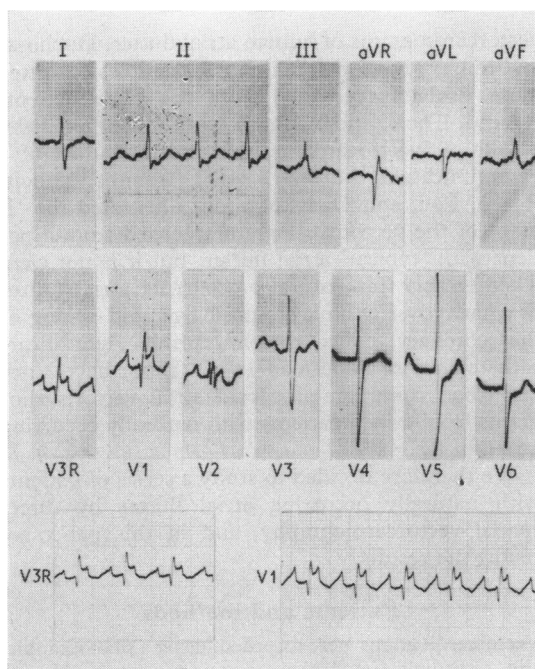


FIG. 2 A form of atypical atrial flutter showing shallow flutter waves in all three standard leads, and prominent flutter waves of 'dome-and-dart' configuration in right praecordial leads.

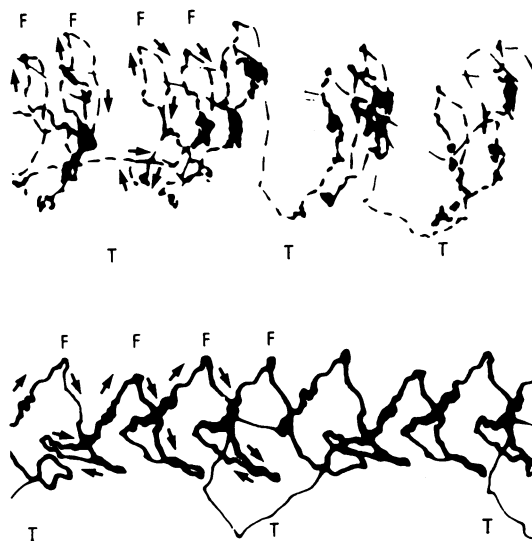


FIG. 3 Déroulé vectorcardiograms recorded at high magnification from two patients with classical atrial flutter. The upper, frontal plane, tracing is interrupted by a blanking pulse every 5 msec. The lower tracing is in the sagittal plane. The direction of inscription of the flutter loops is indicated by arrows. In each strip all or part of three T loops are also present. The associated QRS loops, as seen in Fig. 4, are not evident at this magnification.

the characteristic scalar electrocardiographic features. The flutter waves are best seen in leads II and III which show apparently continuous atrial activity, whereas in lead V1 an isoelectric interval may be present.

The other patient had shallow flutter waves in all 3 standard leads but they were prominent in right praecordial leads and had 'dome and dart' configuration (Mirowski and Alkan, 1967). This is illustrated in Fig. 2.

For the vectorcardiographic recordings, the Frank (1956) system of electrode placement was used. All recordings were made with the patients in the supine posture and with their breath held in mid-inspiration (Maclean, Lowe, and Emslie-Smith, 1970). In the time-marked recordings, the light source was interrupted at intervals of 5 msec. Déroulé vectorcardiographic recordings, with and without time-marking, were made first to determine the course of the flutter loops (Fig. 3). Numerous recordings were then made to capture the flutter vector loops singly in each of the frontal, right sagittal, and horizontal planes (Fig. 4). The greater the variability in the degree of atrioventricular block, the more readily was the triggering mechanism of the vectorcardiograph overcome and the more difficult it became to record complete, single flutter loops. The three planar projections of the vectorcardiogram were recorded successively, because simultaneous recording was not possible with our apparatus. With the help of magnifica-

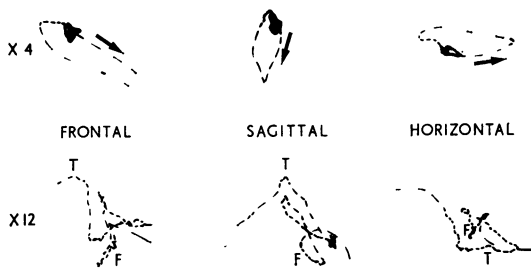


FIG. 4 Planar vectorcardiogram of a patient with classical atrial flutter as actually recorded by the apparatus at two magnifications of the basic standardization of  $1 \text{ cm} = 1 \text{ mV}$ . In the upper set details of the flutter loops are indistinct, but in the lower set the flutter loops (F) can be distinguished from the T loops (T).

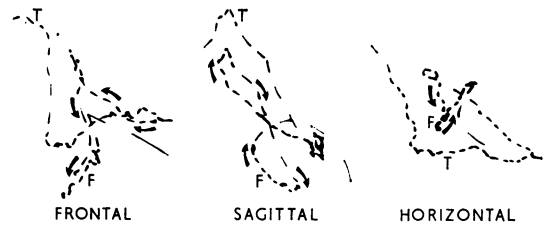


FIG. 5 Photographic enlargement of the F and T portions shown in Fig. 4 clarifies the details of the flutter loops which are used for the spatial reconstructions (Fig. 6).

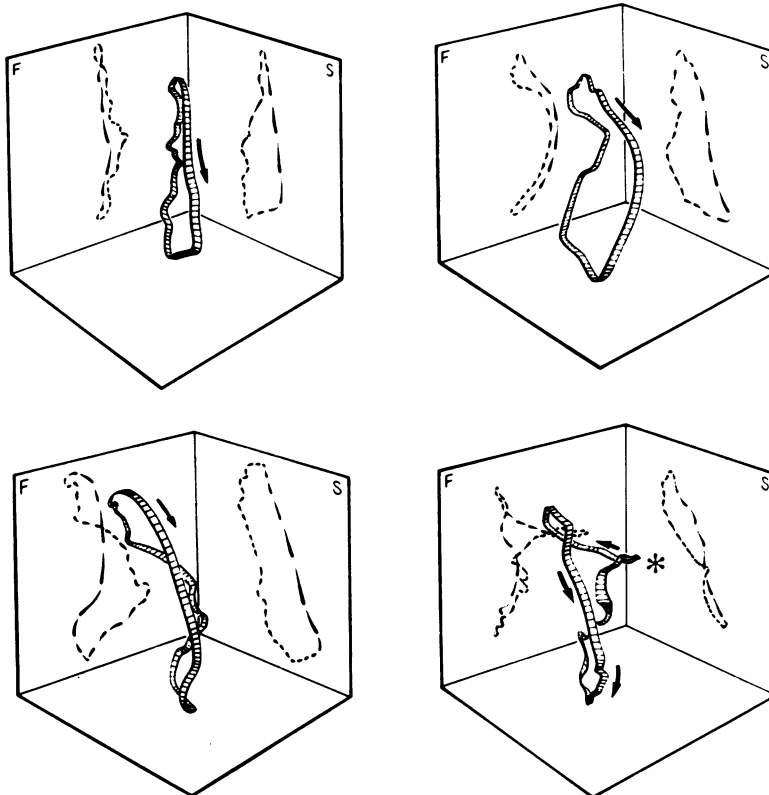


FIG. 6 Spatial atrial flutter loops constructed from the frontal and right sagittal planar projections in four cases of classical atrial flutter. Arrows indicate the direction of inscription of the loops. In one there is a suggestion of a null point on the slowly inscribed ascending part of the loop (\*).

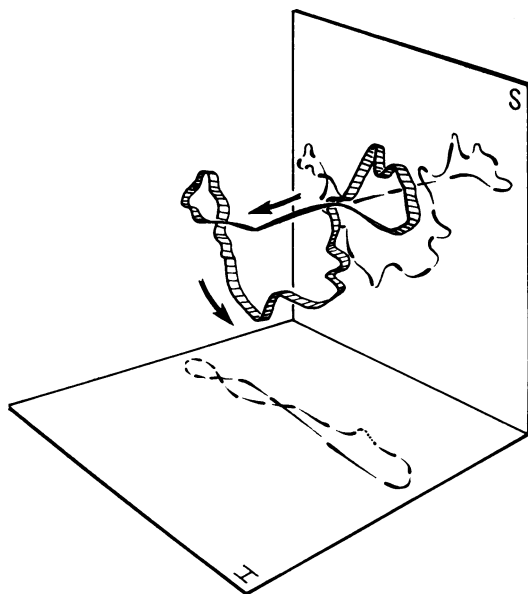


FIG. 7 Spatial atrial flutter loop from the patient whose scalar records showed atypical flutter (Fig. 2). The orientation is almost horizontal in contrast to that of the flutter loops of classical atrial flutter (Fig. 6).

tion of the recorded flutter loops (Fig. 5), the medical artist was then able to construct spatial diagrams of the flutter loops (Fig. 6 and 7).

### Results

The spatial vectorcardiogram of the 12 cases of 'classical' atrial flutter showed flutter loops with their long axes lying in the vertical plane. In the frontal and right sagittal planes they were either of distorted oval, or figure-of-eight, form. In the horizontal plane they were small and difficult to analyse because they failed to show clearly the greater parts of the flutter loops so well seen in the two vertical planes. In the frontal plane they were inscribed usually anticlockwise and in the right sagittal plane clockwise.

It was difficult to ascertain the null point or the presence or absence of short isoelectric intervals and it is to be emphasized that the artist's reconstructions are diagrammatic. However, in some of the actual recordings there is a suggestion of a null point on the slowly inscribed ascending limbs of the flutter loops (Fig. 4, 5, and 6).

Not only do the vectorcardiograms indicate the route of the atrial activation, but they also show a

varying speed of inscription in different planes. The flutter loops characteristically progress more slowly upward than they do in their downward path, as had been suggested by Cabrera and Sodi Pallares (1947). The rapid downward path of the flutter loop is usually to the right of, and always anterior to, the slower upward path.

The vectorcardiogram of the patient whose scalar electrocardiogram had the pattern described as 'flutter of left atrial origin' (Mirowski and Alkan, 1967) showed that the long axis of the flutter loops was anteroposterior in the sagittal and horizontal planes. In these planar projections, the flutter vector loops are of a complex figure-of-eight form. In this case, too, the vector loops have fast and slowly inscribed parts, the rapid backward path being mostly to the right of, and above, the slower forward component. There is again no clear suggestion of any null point, though the complexity of these particular flutter loops would make the certain recognition of one almost impossible (Fig. 7).

### Discussion

In describing the scalar electrocardiographic patterns of atrial flutter occurring in man, the terms 'common' and 'rare' are often used as though they were clearly defined entities, whereas in fact several electrocardiographic patterns have been described. There is unanimity about the so-called 'common', 'classical', or 'typical' type in which the flutter waves are predominantly inverted in leads II, III, and aVF (Lewis, 1925). The 'uncommon', 'rare', or 'atypical' forms do not comprise a single group with common characteristics: examples have been described in which the flutter waves are predominantly upright in leads II, III, and aVF (Bellet, 1971), leads I, II, III, and aVF (Prinzmetal *et al.*, 1952), and leads I, II, and aVL (Latour and Puech, 1957; Puech, Latour, and Grolleau, 1970). Vitek (1967) described the intracardiac electrocardiography of a 'rare' form of flutter in which the flutter waves were best seen in leads I and aVL and were diphasic in right praecordial leads. He considered that there was a downward spread of activation in both the right and left atria. In addition, Mirowski and Alkan (1967) have shown that in both 'common' and 'rare' types the flutter waves may have a 'dome and dart' appearance in lead V<sub>1</sub>.

Oesophageal leads show a caudocephalic spread of activation in the 'common' type and a cephalocaudal direction in the 'rare' type according to Prinzmetal *et al.* (1952). By direct epicardial recording from dogs (Hayden, Hurley, and Rytand, 1967) and in man by intracardiac recording (Giraud, Latour, and Puech, 1955) and by indirect records

from the oesophagus and right atrium (Kishon and Smith, 1969) it has been established that in the 'common' type the path of excitation runs first cranially, probably in the left atrium, and then caudally, probably in the right atrium. These studies accorded with the idea proposed by Cabrera and Sodi Pallares (1947) who used indirect records from the oesophagus and praecordium. Vectorial analysis of such scalar recordings (Cabrera and Sodi Pallares, 1947; Giraud *et al.*, 1955; Kishon and Smith, 1969) have yielded derived, or indirect, vector 'flutter loops' that are all very similar. There seems to be fairly general agreement that the flutter loop lies close to the sagittal plane but slightly tilted from it so that in the frontal plane it is usually inscribed anticlockwise. The posterior part of the loop has an upward direction and the anterior part a downward one. Rytand *et al.* (1966) found that excitation progressed upward in the left atrium during the sharply descending phase of the flutter wave in lead II and downward in the right atrium during the inscription of the blunt summit of the flutter wave in lead II. The indirect (derived) flutter loop is a closed one and there has been doubt about where it began and ended (Cabrera and Sodi Pallares, 1947; Duchosal and Sulzer, 1949). Rytand (1967) studied the spontaneous termination of atrial flutter recorded in scalar leads and found that the isoelectric line following the abrupt resumption of sinus rhythm was near the centre of the flutter wave in leads II and III. This enabled him 'to place the null point centrally in vectorcardiographic analyses of flutter at least in the most valuable longitudinal axis'. He concluded that each flutter cycle ended just before the vector loop turned downward, forward, and to the right. He therefore conjectured that it ended in or near the sinus node and was possibly caused by circus movement in the internodal tracts described by James (1963).

The 3 atrial vectorcardiograms of the 'common' type of flutter published by Alderman *et al.* (1972) show 'rapid, superiorly directed forces corresponding to the notch-to-nadir interval' of the scalar flutter wave, these being 'followed almost immediately by rapid, inferiorly directed forces corresponding to the nadir-to-summit interval'. The inferiorly directed forces were 'anterior and generally to the right of the superiorly directed forces'. Mention was also made of unpublished data which confirmed these findings and that the sagittal loop was the most constant in appearance.

Our direct vectorcardiographic records from the 12 patients with 'classical' flutter resemble the indirect vectors of these earlier workers but they do not help to settle the dispute about whether or not there is a circus rhythm. Even when they appear to

show continuous atrial activity they do not differentiate between depolarization and repolarization. The records from the 'atypical' case are compatible with a circus rhythm but occurring in a plane more inclined to the horizontal than to the vertical. This patient exhibited the pattern of 'dome and dart' flutter waves that Mirowski and Alkan (1967) ascribed to an ectopic focus in the posterior portion of the left atrium. The published reports on 'atypical' flutter are too scanty and confused at present to allow much speculation as to its relation with the 'common' or 'classical' pattern and the need to pay more attention to the less common patterns is obvious.

Stibitz and Rytand (1968) showed that a circus movement giving rise to a family of involutes of the arbitrary central obstacle according to the Huygens principle can explain the course of excitation of the atria observed experimentally in animals. This explanation counters the objections of Rothberger (1922) and Scherf and Schott (1953) to the mother-wave-daughter-wave concept introduced by Lewis, Feil, and Stroud (1920). Guiney and Lown (1972) have recently produced evidence consistent with re-entry as the basic mechanism of human atrial flutter.

Conventional scalar electrocardiograms and vectorcardiograms and proximity electrocardiograms (intracardiac, oesophageal, and praecordial) have failed to differentiate between circus rhythm and a unifocal tachydysrhythmia as the basis of clinical flutter, though they have given much information regarding the pathway of atrial excitation. This is remarkable considering the vast amount of experimentation, speculation, and writing that has occurred since Jolly and Ritchie (1911) first described human atrial flutter.

In experimental animals there are two well-documented models of atrial flutter, namely 'electrical flutter' due to a circus movement (Rosenblueth and Garcia Ramos, 1947) and 'aconitine flutter' due to a unifocal discharge (Scherf, 1947). It is likely that for some time there will remain two schools of thought regarding the mechanism of flutter in man (Katz and Pick, 1960).

In view of the surprising absence of any report of more than 3 examples of directly recorded vectorcardiograms of human atrial flutter, we undertook this investigation, primarily to study the 'common' form. From our more adequate data we have been able to confirm the spatial pathway of the atrial vectorcardiogram in flutter of the 'common' type, and to demonstrate that the pathway was different in one type of 'rare' flutter. In the course of our study we recognized and partly overcame the technical difficulties that may well have prevented

earlier workers from recording satisfactory vectorcardiograms from more than sporadic examples. As a result, we have been able, for the first time, to present three-dimensional reconstructions based upon directly recorded planar atrial vectorcardiograms.

Although we believe we have now adequately described the spatial atrial vectorcardiogram in atrial flutter in man, we think this approach is of limited value in helping to explain its mechanism. The problem will probably remain unsolved until more accurate epicardial mapping of atrial flutter waves is carried out by techniques such as used by Wellens *et al.* (1971). From one case explored at operation, these authors obtained incomplete data that suggested a unifocal discharge from a site in the medial aspect of the right atrium near the aortic root. Their argument, however, is not completely convincing and the problem remains unsolved.

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